VEHICLE TRAJECTORY CONTROL SYSTEM

5 Background of the Invention

Field of the Invention

The present invention relates to a system and
10 method to control a powertrain of a vehicle, and in
particular powertrain control during vehicle
deceleration.

Background of the Invention

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A vehicle powertrain typically includes a power
source such as an internal combustion engine, coupled to
a gearbox such as a transmission with various gear
ratios. A powertrain controller is usually provided
20 which controls the powertrain in part based on a driver's
requests.

In one system, desired powertrain output is
determined based on depression of a pedal by a vehicle
operator. In such a system, a strategy is needed for the
25 situation when a driver releases the pedal, known to
those skilled in the art as a tip-out. During a tip-out,
the driver is indicating a desire for reduced engine
output.

The inventors herein have recognized a
30 disadvantage if conventional methods of powertrain output
control are used during tip-out situations. In
particular, if the accelerator pedal is released and
subsequently engaged, poor drivability may be experienced
due to transmission gears lash. For example, when the

engine transitions from exerting a positive torque to exerting a negative torque (or being driven), the gears in the transmission separate at the zero torque transition point. Then, after passing through the zero

5 torque point, the gears again make contact to transfer torque. This series of events produces an impact, or clunk, resulting in poor drivability and customer dissatisfaction. In other words, the engine first exerts a positive torque through the torque converter onto the

10 transmission input gears to drive the vehicle. Then, in response to the driver tip-out, the engine is driven by the torque from the transmission through the torque converter. The transition between these two modes is the point where the engine is producing exactly zero engine

15 brake torque. Then, at this transition point, the gears in the transmission separate because of inevitable transmission gear lash. When the gears again make contact, they do so dynamically, resulting in an undesirable impact.

20 This disadvantage is exacerbated when the operator returns the accelerator pedal to a depressed position, indicating a desire for increased powertrain output. In this situation, the zero torque transition point must again be traversed. However, in this

25 situation, the engine is producing a larger amount of torque than during deceleration because the driver is requesting acceleration. Thus, another, more severe, impact is experienced due to the transmission lash during the zero torque transition.

30 The inventors herein have recognized another disadvantage if conventional methods of powertrain output control are used during tip-out situations. In particular, different vehicle trajectories are obtained depending on road grade. Stated another way, if a

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desired powertrain output torque is requested, different
vehicle deceleration rates are obtained depending on road
grade. At steep down grades, the vehicle may accelerate
even if negative powertrain torque is requested due to
5   vehicle mass. If the conventional control strategy is
changed to minimize this acceleration on down grades,
then excessive deceleration is obtained on flat road
grades. Thus, drive performance is sacrificed under one
driving condition or another.
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SUMMARY OF THE INVENTION

The disadvantages of prior approaches are
overcome by a method for controlling a powertrain coupled
15   to a vehicle, the powertrain having an internal
combustion engine coupled to a transmission, the vehicle
operated by a driver. The method comprises determining a
desired vehicle trajectory, adjusting an engine operating
parameter to maintain positive powertrain output when an
20   actual vehicle trajectory is below said desired vehicle
trajectory, and adjusting said engine operating parameter
to transition from positive powertrain output to negative
powertrain output when said actual vehicle trajectory is
above said desired vehicle trajectory.
25   By maintaining positive powertrain output when
an actual vehicle trajectory is below said desired
vehicle trajectory, it is possible to prevent
transmission separation and "clunk." For example, during
a tip-out, if actual vehicle acceleration is less than
30   desired vehicle acceleration, then it is not necessary to
provide negative powertrain torque, and positive torque
can be maintained to prevent "clunk."
Alternatively, by transitioning from positive
powertrain output to negative powertrain output when

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actual vehicle trajectory is above said desired vehicle trajectory, it is possible to provide the desired vehicle trajectory, i.e., drive feel may be optimized by allowing a transition through zero torque but maintaining the

5   vehicle trajectory. Stated another way, a transition through zero torque is allowed to maintain a desired vehicle trajectory.

An advantage of the invention is minimum transitioning from positive to negative torque, thereby

10 minimizing clunk.

Another advantage of the invention is that transitions from positive to negative torque are performed when necessary to maintain a desired vehicle trajectory. Thus, improved vehicle drivability is

15 obtained.

Yet another advantage of the present invention is that when a transition from positive to negative torque is necessary, a smooth transition is achieved.

It is also important to note that the desired

20 vehicle trajectory can include various parameters such as, for example, a desired vehicle acceleration or deceleration, or a desired vehicle speed. Further, various engine operating parameters can be used to maintain positive powertrain output such as, for example,

25 engine airflow, engine air/fuel ratio, engine torque, or engine ignition timing.

BRIEF DESCRIPTION OF THE DRAWINGS

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Figures 1-2 are block diagrams of an embodiment wherein the invention is used to advantage;

Figures 3-18 are high-level flow charts of various operations performed by a portion of the

35 embodiment shown in Figure 1;

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Figure 19 is a graph illustrating operation according to the present invention; and

Figures 20-23 are block diagrams of torque converters that can be used according to the present invention.

DETAILED DESCRIPTION

Referring to Figure 1, internal combustion engine 10, further described herein with particular reference to Figure 2, is shown coupled to torque converter 11 via crankshaft 13. Torque converter 11 is also coupled to transmission 15 via transmission input shaft 17. Torque converter 11 has a bypass clutch (described in Figures 20-23), which can be engaged, disengaged, or partially engaged. When the clutch is either disengaged or partially engaged, the torque converter is said to be in an unlocked state. Transmission 15 comprises an electronically controlled transmission with a plurality of selectable discrete gear ratios. Transmission 15 also comprises various other gears such as, for example, a final drive ratio (not shown). Transmission 15 is also coupled to tire 19 via axle 21. Tire 19 interfaces the vehicle (not shown) to the road 23. In a preferred embodiment, transmission 15 has the following driver selectable options: park (P), reverse (R), neutral (N), driver (D), and low (L). The driver selects these positions via a transmission lever. In this preferred embodiment, the lever is known as the PRNDL lever, corresponding to the different options. In particular, in park or neutral, transmission 15 does not transmit torque from the transmission input to the output. In drive, a transmission controller can control transmission to select any available forward gear ratios.

In reverse, a single reverse gear is selected. In low, only a lower set of forward gear ratios can be selected by the electronic controller. Those skilled in the art will recognize, in view of this disclosure, various other types of transmission levers with different sets of options that can be used with the present invention. For example, there can be low 1 and low 2 options. Also, the transmission lever may be located on a steering column or between driver and passenger seats.

Internal combustion engine 10 comprises a plurality of cylinders, one cylinder of which is shown in Figure 2. Electronic engine controller 12 controls Engine 10. Engine 10 includes combustion chamber 30 and cylinder walls 32 with piston 36 positioned therein and connected to crankshaft 13. Combustion chamber 30 communicates with intake manifold 44 and exhaust manifold 48 via respective intake valve 52 and exhaust valve 54. Exhaust gas oxygen sensor 16 is coupled to exhaust manifold 48 of engine 10 upstream of catalytic converter 20.

Intake manifold 44 communicates with throttle body 64 via throttle plate 66. Throttle plate 66 is controlled by electric motor 67, which receives a signal from ETC driver 69. ETC driver 69 receives control signal (DC) from controller 12. Intake manifold 44 is also shown having fuel injector 68 coupled thereto for delivering fuel in proportion to the pulse width of signal (fpw) from controller 12. Fuel is delivered to fuel injector 68 by a conventional fuel system (not shown) including a fuel tank, fuel pump, and fuel rail (not shown).

Engine 10 further includes conventional distributorless ignition system 88 to provide ignition spark to combustion chamber 30 via spark plug 92 in

response to controller 12. In the embodiment described herein, controller 12 is a conventional microcomputer including: microprocessor unit 102, input/output ports 104, electronic memory chip 106, which is an

5   electronically programmable memory in this particular example, random access memory 108, and a conventional data bus.

Controller 12 receives various signals from sensors coupled to engine 10, in addition to those

10   signals previously discussed, including: measurements of inducted mass air flow (MAF) from mass air flow sensor 110 coupled to throttle body 64; engine coolant temperature (ECT) from temperature sensor 112 coupled to cooling jacket 114; a measurement of throttle position

15   (TP) from throttle position sensor 117 coupled to throttle plate 66; a measurement of turbine speed (Wt) from turbine speed sensor 119, where turbine speed measures the speed of shaft 17; and a profile ignition pickup signal (PIP) from Hall effect sensor 118 coupled

20   to crankshaft 13 indicating and engine speed (N).

Continuing with Figure 2, accelerator pedal 130 is shown communicating with the driver's foot 132. Accelerator pedal position (PP) is measured by pedal position sensor 134 and sent to controller 12.

25   In an alternative embodiment, where an electronically controlled throttle is not used, an air bypass valve (not shown) can be installed to allow a controlled amount of air to bypass throttle plate 62. In this alternative embodiment, the air bypass valve (not

30   shown) receives a control signal (not shown) from controller 12.

Figures 2-17 describe various routines carried out by controller 12. The routines are preferably carried out in the order in which they are numbered,

unless called by an earlier routine. However, those
skilled in the art will clearly recognize, in view of
this disclosure that various aspects of the Figures and
various calculations can be rearranged in numerous orders
5   without departing from the scope of the invention.

Referring now to Figure 3, a routine is
described for determining the desired engine torque for
use in the engine control system. First, in step 310, a
driver requested wheel torque, or output shaft torque, is
10   calculated based on pedal position and vehicle speed. In
particular, the driver requested torque (tqo_arb_req) is
calculated as a two-dimensional lookup table as a
function of pedal position (PP) and vehicle speed (vspd).
Next, in step 312, a limit torque (tqo_arb_lim) is
15   determined. This limit output torque can be provided
from various sources, for example, from vehicle speed
limiting, traction control limiting, or from a vehicle
stability control system. When the transmission
controller provides the limit output torque, this torque
20   can represent maximum allowable torque that can be
transmitted through the transmission. Next, in step 314,
the routine calculates a driver engine torque request for
manual transmissions and automatic transmissions in
neutral, park, or some driver selected gears
25   (tqe_dd_req). Note that the tqe_dd_req is a separate
parameter then the one calculated in step 310, when
tqe_arb_req is calculated for automatic transmissions
when the transmission is in a gear other then neutral or
park. Next, in step 316, the routine converts driver
30   wheel torque request and limit torque to engine torque
request using overall ratio G1 (which includes gear
ratio, torque converter torque ratio, transmission
efficiency), and torque loss parameter LOSS, which
preferably represent friction. Next, in step 318, the

routine selects the maximum of the tqe_dd_req and tqe_arb_req. In this way, the routine arbitrates the proper engine torque request taking into account whether an automatic transmission or manual transmission is present in the vehicle. Further, the routine provides for automatic transmissions operated in a mode, such as neutral or park, when the engine is not coupled to drive the wheels.

Referring now to Figures 4A and 4B, a routine is described which calculates a desired vehicle speed trajectory and which filters and limits the torque request to provide various advantages as described later herein. First, in step 410, a routine calculates the vehicle speed trajectory based on position of the gear selector (PRNDL), vehicle speed (vspd), and the brake pedal (BOO).

In particular, the routine calculates the maximum vehicle speed during a tip-out (tq_vs_des_mx). As described later herein, this vehicle speed trajectory is used to determine whether negative engine torque is required. Those skilled in the art will recognize, in view of this disclosure, that various other parameters can be used to provide a desired vehicle trajectory such as acceleration or deceleration. Alternatively, timers could be used to determine if a selected operating conditions is achieved by a set time.

Continuing with Figure 4A, the routine proceeds to step 412 where a determination is made as to whether the pedal position is at closed pedal. This is done, for example, by checking the flag APP. Flag APP is set to minus 1 when, for example, PP is less than a predetermined value indicated the driver has released their foot, or when the pedal angle is almost completely released. In other words, in this implementation, the

routine determines whether the driver has positioned the pedal in the most released position, known to those skilled in the art as closed pedal. When the answer to step 412 is yes, the routine continues to step 414 where

5   the desired engine torque is rate limited. Then, in step 416, the requested torque is limited to a minimum of zero. Parameter tqe_daspot represents the minimum clip on requested torque. The equation in step 414 provides a second order function, which is preferable for drive

10 feel. Those skilled in the art will recognize, in view of this disclosure, that various filtering methods could be used, such as a first order low pass filter or a rate-limiting filter.

When the answer to step 412 is no, the routine

15 continues to step 430 in Figure 4b. In other words, when the driver is not in a closed pedal condition, which means in a part or wide-open pedal position, the routine calculates the rate limited torque as a portion of the difference between the current driver demand and the

20 minimum allowed torque (tqe_desmaf) determined in part from the misfire line as described later herein. Next, in step 432, a determination is made as to whether temporary filtered torque (tqe_daspot_tmp) is greater then filtered desired torque (tqe_daspot). Depending on

25 the outcome of step 432, a temporary multiplier is set. In particular, this temporary multiplier adjusts a filtering time constant for filtering engine torque. The filter constant is set to different levels depending on whether desired engine torque is increasing or

30 decreasing. Step 434 sets the multiplier for an increase in torque. Step 436, sets the multiplier for a decrease in desired torque. Steps 438, 440, and 432 describe the details of how the desired engine torque is filtered. The time constant (tcdasf) is calculated in step 438.

Then, the filter constant is calculated as a function of the sample time and the parameter (tcdasf). Finally, in step 442, the filtered desired engine torque is calculated with a low pass filter (LPF). Those skilled

5   in the art will recognize, in view of this disclosure that various types of filters can be used rather than a low pass filter such as rate limiting filters, or lead lag filters.

Referring now to Figure 5, a routine is
10 described which continues the determination of desired engine torque from Figures 4a and 4b. First, in step 510, a determination is made as to whether the requested engine torque from step 318 (tqe_arb_req) is less than the filtered desired engine torque (tqe_daspot). When
15 the answer to step 510 is no, the routine continues to step 512 when a flag (tq_dd_limit) is set to zero. Otherwise, in step 514, the desired engine torque is set equal to the filtered engine torque. Next, in step 516, the flag (tq_dd_limit) is set to minus one. In this way,
20 regardless of pedal angle, the filtered engine torque is applied as a minimum clip on the driver requested engine torque.

Referring now to Figure 6, a routine is described for determining whether the driver is in a
25 closed pedal position, wherein closed pedal engine and vehicle controls are executed. First, in step 610, a flag is initialized (tq_dd_mode = zero). This step is only executed at key-on or at part throttle conditions. This flag is used in the closed pedal state machine to
30 determine which state is executed. As described later herein, the state machine operates from case zero up to case 6. The flag tq_dd_mode determines which case is executed.

In step 612, a determination is made as to whether a tip out condition is present via flag APP. In other words, a determination is made as to whether the measured accelerator pedal position is less than a

5 predetermined value indicating the pedal is in the fully released position. Those skilled in the art will recognize, in view of this disclosure, various ways for determining whether a closed pedal, or tip-out condition, is present. For example, vehicle speed or acceleration,

10 engine torque determination, or various other methods could be used.

Continuing with Figure 6, when the answer to step 612 is no, the routine determines that the condition is part throttle or wide-open throttle and executes the

15 routine described in Figure 14. When the answer to step 612 is yes, the routine continues to step 614, where a determination is made as to whether the flag trg_n_t_flg is TRUE. In other words, the routine determines whether the engine is in the feedback engine speed control mode.

20 There are various places where the engine is in the closed loop engine speed control mode such as, for example, during a manual pull in when the transmission requests an engine speed to match the future gear ratio; when the current gear does not provide engine braking as

25 described later herein; or during a neutral to drive engagement. For example, during a neutral to drive engagement or a manual pull in (where the driver changes the selected PRNDL position), the transmission can delay the actual gear change until the engine speed is brought

30 to a desired engine speed. In these examples, the desired engine speed can be selected to equal the synchronous speed in the future gear ratio. In this way, transmission wear is minimized since the gear ratio can be performed with the engine speed close to the engine

speed that will be achieved after the gear change is completed. In another example relating to when the current gear does not provide engine braking, the desired engine torque is calculated to that the transmission

5 input speed is at, or slightly below, the measured transmission output speed times the current gear ratio of the transmission. In this way, there is no delay and transmission gear clunk is minimized when positive powertrain output torque is again applied. Stated

10 another way, the desired engine speed can be set to (or slightly below) the synchronous speed, where the synchronous speed is based on the transmission state (selected gear ratio) and the transmission output speed. Such a method can be used when the current selected

15 transmission ratio does not provide engine braking. In this speed control, as described later herein, a desired torque is selected to cause the speed error to approach zero. As described, torque control can be accomplished via various engine-operating parameters such as air/fuel,

20 ignition timing, throttle angle, or any other available torque actuator.

When the answer to step 614 is no, the state machine is called and the case is executed which corresponds to the current condition of flag tq_dd_mode

25 in step 616. Otherwise, the routine continues to 618 where the flag is set to 7. Then, the desired engine torque is calculated using a PI controller known to those skilled in the art as a proportional integral controller based on an engine speed error calculated from the

30 difference between the desired engine speed (Ndes minus N).

Referring now to Figure 7, case zero of the state machine is described. Case zero is generally called to initialize the state machine. First, in step

710, a determination is made as to whether the requested arbitrated torque is greater than a small positive calibratable engine torque (TQE_SML_POS). When the answer to step 710 is yes, the state machine flag is set to 1 in step 712. Otherwise, the state machine flag is set to 2 in step 714.

Referring now to Figure 8, case 1 of the state machine is described. As described above, case 1 is called when flag tqe_dd_mode is equal to 1 in step 616. In step 810, a determination is made as to whether the desired engine torque is less than or equal to the calibratable small positive torque (TQE_SML_POS). When the answer to step 810 is yes, the flag tqe_dd_mode is set to 2 in step 812.

Referring now to Figure 9, case 2 of the state machine is described. First, in step 910, a determination is made as to whether the current actual vehicle speed (vspd) is greater than the sum of the maximum allowed speed during the tip out condition (tq_vs_des_mx) plus the allowed over-speed error (vsdeltogoneg). The allowed over-speed error can be a single value or can vary with engine operating parameters. For example, depending on selected gear ratio and vehicle speed, it may be desirable to have different thresholds of allowed over-speed error. Such an approach may reduce excessive shifting, also known as shift busyness. When the answer to step 910 is yes, the state machine flag (tq_dd_mode) is set equal to 3. In other words, when the actual vehicle speed is greater than the desired vehicle speed trajectory, plus the tolerance value, the state machine then executes in the next call of step 616, case 3, which executes a torque crossing from positive powertrain output torque to negative powertrain output torque, as described later

herein with particular reference to Figure 10. As described above, those skilled in the art will recognize, in view of this disclosure that various other vehicle parameters can be used to calculate the desired vehicle speed trajectory and determine if the actual vehicle trajectory is below the desired vehicle trajectory.

When the answer to step 910 is no, the routine continues to step 914, where a determination is made as to whether the torque converter is locked. When the answer to step 914 is no, the routine continues to step 918. In step 918, a positive output torque is provided including closed loop control using torque converter input and/or output speeds. In this particular case, a desired engine speed is calculated to be greater than the measured torque converter output or turbine speed. This desired engine speed is used with a closed loop proportional integral (PI) controller to calculate a desired engine torque request. In this way, feedback control is used to maintain a positive output torque. The parameter (TQ_N_SML_POS) is a calibratable parameter to provide a safety factor that minimizes inadvertent zero torque crossings due to external factors such as road grade. In other words, the controller's objective is to maintain engine speed greater than torque converter output speed. Those skilled in the art will recognize in view of this disclosure that additional feedback can be included, wherein such feedback could be from sensors such as a torque sensor, mass airflow sensor, or other sensors used in torque or speed control.

Alternatively, when the torque converter is locked, the desired arbitrated engine torque is set to the small positive torque (TQE_SML_POS). In this case, the powertrain is controlled to provide a positive output torque and minimize inadvertent transitions through the

zero torque point. Since the torque converter is locked, an open loop control approach is used where feedback from torque converter input and output speeds based on a torque converter model are not used. However, other

5   feedback variables can be used in providing the torque control such as, for example, a torque sensor or a mass airflow sensor. In particular, torque transmitted by the powertrain (engine output torque, transmission torque, or wheel torque) can be estimated based on operating

10 conditions such as, for example, mass airflow, manifold pressure, engine speed, ignition timing, coolant temperature, and other operating conditions.

By providing such control of maintaining positive powertrain output, inadvertent zero torque

15 crossings will be minimized and improved vehicle drive feel can be achieved.

Referring now to Figure 10, case 3 of the state machine is described. First, in step 1010, a determination is made as to whether the arbitrated

20 requested engine torque is less than a small negative output torque (TQE_SML_NEG), or the small negative torque is a predetermined calibratable parameter. When the answer to step 1010 is yes, then the state machine flag tq_dd_mode is set to 4 in step 1012. Otherwise, in step

25 1014, the requested engine torque is slowly decremented to gently pass through the zero torque point. In this way, once the negative engine torque is provided, the routine will transition to case 4, and until the negative engine torque is provided, the routine will provide a

30 gradual decrease from the small positive torque to the small negative torque so that clunk occurring at the zero torque point is minimized.

Referring now to Figure 11, case 4 of the state machine is described. First, in step 1110, a

determination is made as to whether a large negative
engine torque is required by determining if flag
(rdy_very_neg) is TRUE. Typically, the flag is set TRUE
by the transmission control system to indicate that the
torque converter is locked. In other words, various
types of torque converters cannot be locked when the
powertrain is transmitting large negative torques. Thus,
the present invention can prevent large negative engine
torques until the torque converter is locked, if such a
torque converter is used. When the answer to step 1110
is yes, the state machine flag (tq_dd_mode) is set to 5
in step 1112. Otherwise, a determination is made as to
whether the torque converter is locked in step 1114.
When the torque converter is locked, the required engine
torque is set to a small negative value (TQE_SML_NEG),
which is predetermined calibratable value. In step 1116,
the negative engine torque is provided in an open loop
mode without feedback from the torque converter input and
output speeds. Otherwise, in step 1118, closed loop
engine speed control is provided where the desired engine
speed is calculated to be slightly less than the torque
converter output speed. Thus, in step 1118, feedback
from the torque converter input speed and output speed is
utilized to minimize inadvertent zero torque transitions.

Referring now to Figure 12, case 5 of the state
machine is described. In step 1210, a determination is
made as to whether the current vehicle speed (vspd) is
greater than the maximum allowed vehicle speed trajectory
value (tq_vs_des_mx). When the answer to step 1210 is
yes, the routine continues to step 1212 where state
machine flag (tq_dd_mode) is set to 6.

Referring now to Figure 13, case 6 of the state
machine is described. First, in step 1310, a
determination is made as to whether measured vehicle

speed (vspd) is less than equal to the desired vehicle speed trajectory plus a predetermined calibratable value (TQ_VS_DESHYS). When the answer to step 1310 is yes, the routine continues to step 1312 where the state machine flag (tq_dd_mode) is set to 5. Otherwise, the routine continues to step 1314 where feedback control vehicle speed is executed to provide the desired deceleration rate and the desired vehicle speed trajectory. In particular, a PI controller known to those skilled in the art as a proportional integral controller is used with the desired maximum allowed vehicle speed and the actual speed to calculate the desired engine torque. In this way, engine torque control is provided to give a desired vehicle trajectory.

If the state machine is called and none of the cases are executed, the default case is case zero.

Referring now to Figures 14a and 14b, a routine is described for rate limiting desired engine torque when desired powertrain output is increasing. In step 1410, a determination is made as to whether the desired engine torque is greater than the current requested engine torque. In other words, a determination is made as to whether the desired engine output is increasing. When the answer to step 1410 is yes, a determination is made in step 1412 as to whether the current engine requested torque is less than or equal to a small negative torque value (TQE_SML_NEG). When the answer to step 1412 is yes, the routine continues to step 1414, where the desired engine torque is rate limited at a first rate determined by function G1. In other words, when the desired engine torque is increasing but negative and less than a predetermined negative engine torque, the desired engine torque increasing rate is limited to a first predetermined rate, wherein the predetermined rate is

dependent on the transmission gear selected or the current transmission gear ratio. When the answer to step 1412 is no, the routine continues to step 1416, where a determination is made as to whether the current requested

5   engine torque is less than a small positive calibratable value (TQE_SML_POS). In other words, a determination is made as to whether the current requested engine torque is near the zero torque point. When the answer to step 1416 is yes, the routine continues to step 1418, where the

10 desired engine torque increasing rate is limited based on function G2. Generally, the maximum allowed rate of increase of engine torque in this region (near the zero torque point) is less than the allowed increasing engine torque rate outside of this region. When the answer to

15 step 1416 is no, the routine continues to step 1420, where engine torque increasing rate is limited to a third predetermined rate based on function G3. Stated another way, that allowed increasing rate of torque is greater when for the regions away from the zero torque region.

20   In this way, the present invention provides for three different engine increasing torque rate limits depending on the current engine torque value. In particular, when desired engine torque is increasing and a large negative value, it is rate limited at a first

25 value. When desired engine torque is increasing near zero torque point, it is rate limited at a second, generally lower rate. Finally, when desired engine torque is increasing and a large positive value, it is rate limited at a third rate. In addition, any

30 combination of the above three rate limits may be used. For example, engine torque may be limited only when transitioning through the zero torque point, or engine torque may be limited only when transitioning through the zero torque point and when increasing above zero torque,

engine torque may be limited only when transitioning through the zero torque point and when increasing below zero torque. Additionally, rate limits can be set as a function of the current, or selected, gear ratio, since

5   different rate limits may be appropriate depending on the actual transmission gear, or based on the selected gear as indicated by the transmission lever (PRNDL). Also, as described herein, rate limiting may be used for decreasing torque when passing through the zero torque

10   region.

From step 1414, the routine continues to step 1422, where a determination is made as to whether the current requested engine torque is greater than the rate limited engine torque. When the answer to this is yes,

15   the desired engine torque is set equal to the rate limited torque and a rate limiting flag (tq_dd_limit) is set to 1. Otherwise, the flag is set to zero in steps 1424 and 1426. From step 1418, the routine continues to step 1428, where the same determination as step 1422 is

20   made. When the answer to step 1428 is yes, the desired engine torque is set equal to the rate limited engine torque and the flag (tq_dd_limit) is set to 2 is step 1430. Otherwise, in step 1432, the flat is set to zero. From step 1420, the same determination as in steps 1422

25   and 1428 is made in step 1434. When the answer to step 1434 is yes, the desired engine torque is set to equal to the rate limited value and the flag is set to 3 in step 1436. Otherwise, in step 1438, the flag is set to zero.

Referring now to Figure 15, a routine is

30   described for arbitrating between various torque limits and the desired rate limited torque request. In steps 1510, 1512, and 1514, the rate limited desired engine torque request is compared with the various maximum torque limits that prevent engine speed from becoming

greater than a predetermined value (tqe_rpm_lim) and which prevent torque being requested which is greater than the maximum allowable torque transmitted through the transmission (tqe_max_tran).

Referring now to Figures 16a and 16b, a routine is described for controlling engine torque while maintaining a minimum airflow requirement. In particular, the following routine provides a method to prevent engine stalls when there is a rapid decrease in required engine torque.

First, in step 1610, anti-stall torque line (tqe_antistal) is calculated, which is the minimum indicated torque allowed as a function of engine speed minus desired idle speed and the torque control source (tq_source). Parameter tq_source is the dominant determinant of the torque reduction, i.e., whether vehicle speed limiting, traction control, or shift modulation are limiting torque. Thus, since depending on which limit is controlling, a more aggressive position can be taken on how close to the anti-stall torque line the engine is operated.

Next, in step 1612, the desired engine torque arbitrated request is compared with the anti-stall torque line and the maximum of these parameters is selected. Next, in step 1614, the equivalent indicated engine torque at the minimum allowed airflow and mapped spark value below which engine misfires occur is called. This value is determined as a function of engine speed. Next, in steps 1616 and 1618, the transform of engine required idle airflow is determined. First, a multiplier (idle_am_mul) is determined as a function of the difference between the desired engine speed and the actual engine speed, and the difference between the current vehicle speed and a minimum vehicle speed at

which idle speed control is engaged (minmph). Figure 16c illustrates an example table showing that as the difference in vehicle speed or difference in engine speed becomes smaller, the minimum allowed airflow is gradually adjusted to become equal to the airflow required at idle conditions.

Then, in step 1618, the multiplier is used to adjust the required airflow to maintain a desired engine speed at idle conditions. Then, in step 1619, this adjusted airflow is converted to a load value by dividing by the number of cylinders (numcyl_0), engine speed (N), and the amount of air that fills the cylinder at standard temperature and pressure (sarchg). Next, in step 1620, this desired load is converted to a torque using the conversion factor (TQ_2_LOAD). Finally, in step 1622, the maximum of the torque due to minimum airflow from misfires and the torque due to the minimum air to guarantee engine idle speed control is selected.

Continuing with Figure 16b, this selected torque is then converted to an airflow request in step 1624. Next, in step 1626, this selected torque request is converted from an indicated torque to an engine brake torque request by subtracting the torque losses (tqe_los). Finally, in step 1634, the engine torque request for scheduling the required airflow for the electronic throttle control system is selected at the maximum of the parameter determined in step 1626 and the current engine brake request.

In this way, according to the present invention, when engine and vehicle operating conditions are away from an idle speed control range, engine airflow can be reduced below the required engine airflow for maintaining idle speed. In this way, it is possible to provide large negative engine brake torques to maintain

vehicle trajectory under a variety of vehicle operating conditions. However, as the vehicle conditions approach an engine idle speed region, airflow is increased to a required engine idle speed control level. In this way,

5   even despite the engine airflow delays due to manifold volume, it is possible to maintain robust idle speed control as well as provide large negative engine braking ability.

Referring now to Figure 17, a routine is

10 described for calculating a desired vehicle trajectory, which is called in step 410 of Figure 4a. First, a determination is made as to whether flag (APP) is less than zero. In other words, a determination is made in step 1710 as to whether a closed pedal (tip-out

15 condition) is present. When the answer to step 17 is yes, the desired closed pedal acceleration (ct_accl_des) is calculated as a function of the current vehicle speed and the gear selected position (PRNDL). Next, in step 1714, a determination is made as to whether the brake

20 pedal is released. When the answer to step 1714 is yes, a determination is made as to whether the brake pedal engagement duration (boo_duration) is greater than zero in step 1716 indicating the first pass through the routine since the brake was depressed. When the answer

25 to step 1716 is yes, the vehicle speed release value (vs_on_release) is set equal to the current vehicle speed and the last brake engagement duration is set equal to the current brake engagement duration value in step 1718. Next, in step 1720, a determination is made as to whether

30 the first brake engagement duration (boo_1st) is greater than a predetermined duration (tq_boo_long) and the flag (tq_frz_vsboo) is true. Flag (tq_frz_vsboo) is a selection flag that allows using brake duration in determining the maximum allowed vehicle speed trajectory.

Parameter (tq_boo_long) represents the braking duration after which the maximum allowed vehicle speed trajectory will be held constant. In other words, if the driver simply taps the brake, the maximum allowed vehicle speed will continue to ramp toward zero after the brake is released. However, if the driver holds the brake pedal for longer than a predetermined value, the maximum allowed vehicle speed is held to the vehicle speed when the brake was released. This can give the driver the ability to set a desired speed using the brake on a long downhill grade.

Continuing with Figure 17, when the answer to step 1720 is yes, the maximum allowed vehicle speed is set to parameter vs_on_release in step 1722. When the answer to step 1720 is no, the maximum allowed vehicle speed is set to the previously set maximum allowed vehicle speed plus a desired acceleration times the sample time in step 1724. Step 1724 represents where maximum allowed vehicle speed is gradually ramped toward zero.

When the answer to step 1710 is no, the brake engagement duration and the first brake engagement duration are both set to zero and the desired maximum vehicle speed is set to the current vehicle speed in step 1720. When the answer to step 1714 is no, the maximum desired vehicle speed is set to the current vehicle speed and the brake engagement duration is incremented by sample time in step 1722.

In this way, the desired vehicle trajectory is determined based on the current vehicle speed and the position of the gear selector (PRNDL). Further, the desired vehicle trajectory is adjusted based on actuation or engagement of the brake pedal. In particular, the length of engagement of the brake pedal is used to adjust

the desired vehicle trajectory. For example, the desired
vehicle speed trajectory is decreased while the brake
pedal is engaged and set to the value of the actual
vehicle speed when the brake pedal is released in some
cases. In this way, improved drive performance can be
achieved since all parameters indicative of the driver's
desired vehicle operation are being incorporated.

Referring now to Figure 17B, an example of
operation is described while the accelerator pedal is
released (i.e., closed pedal operation). The top graph
shows the brake actuation signal and the bottom graph
shows the maximum allowed vehicle speed trajectory. At
time t1, the brake is depressed and released at time t2.
While the brake is pressed the maximum allowed vehicle
speed is set to the current vehicle speed, and thus no
control action is taken. Since time difference $\Delta t1$ is
less than the predetermined brake duration, the ramping
of the maximum allowed vehicle speed is then continued
until the brake is depressed again at time t3. The brake
is then released at time t4. Since time difference $\Delta t1$
is greater than the predetermined brake duration, the
vehicle speed upon release at time t4 is captured and
held as the maximum allowed vehicle speed.

Referring now to Figure 18, a routine is
described for determining, in some cases, whether the
torque converter should be locked. In particular, the
routine determines whether the torque converter can be
locked during a closed pedal operation. First, in step
1810, a determination is made as to whether the state
machine is in case 3 and whether the torque converter is
presently unlocked. When the answer to step 1810 is yes,
the torque converter can be locked in step 1820. In
other words, the torque converter can be locked when the
engine torque is less than a small, predetermined

negative torque value. In other words, the torque
converter can be locked after the vehicle has
transitioned through the zero torque point. This is
especially advantageous if it is desired to unlock the
5   torque converter when the driver again depresses the
accelerator pedal and requests positive powertrain
output. In particular, under this situation, the torque
converter can be unlocked and thus provide a rapid amount
of powertrain output, thus improving vehicle performance
10   feel.

Referring now to Figure 19, a graph
illustrating typical operation according to the present
invention is shown. The graph plots engine brake torque
versus time for a tip-out. The dash line illustrates the
15   desired engine torque value determined from, for example,
the driver actuated element. The solid line indicates
the actual engine torque produced. At time T1, the
driver releases the foot pedal and the tip-out situation
is begun. The algorithms, according to the present
20   invention as described herein, first reduce the engine
torque by a predetermined amount. Then, the engine
torque is gradually decreased at a predetermined rate,
which is determined by a selected tip-out torque decrease
trajectory. The engine torque is decreased until it
25   reaches a small positive value (TQE_SML_POS).
Maintaining the torque converter input speed greater than
the torque converter output speed holds this small
positive torque. Then, at time T2, there is a decision
to provide negative engine torque based on the vehicle
30   trajectory. In particular, at time T2, the actual
vehicle speed becomes greater than the maximum allowed
vehicle speed plus a predetermined calibratable value.
Starting at time T2, the engine torque is gradually
decreased at a predetermined rate through the zero torque

point. Also, in this region, torque line can be used using the torque converter input and output speeds to learn the zero torque point and to update the engine torque model. Then, at time T3, a small negative torque

5   is held by maintaining the torque converter output speed greater than the torque converter input speed. This small negative torque is held for a short period until, at time T4, a decision is made to lock the torque converter to provide high levels of negative torque. At

10   time T4, the torque converter is locked. Then, the negative torque level is selected to maintain the desired vehicle speed trajectory. The negative torque level is selected such that the actual vehicle speed is generally below the maximum allowed vehicle speed.

15   Referring now to Figures 20 and 21, two circuit torque converter 11a is shown. Figure 20 shows the two circuit torque converter clutch disengaged, while Figure 21 shows the two circuit torque converter clutch engaged. Two circuit torque converter 11a is shown having input

20   shaft 13a, which is coupled to engine crankshaft 13, and output shaft 17a, which is coupled to transmission input shaft 17. Two circuit torque converter 11a has converter clutch 200a. Two circuit torque converter 11a is disengaged by supplying pressure to the clutch control

25   side of the clutch. The pressure is exhausted through the impeller side of the converter. The exhaust fluid is sent to a cooler. In particular, the clutch control pressure must work against the pumping action of the impeller. To apply the converter clutch, fluid flow is

30   reversed.

          Referring now to Figures 22 and 23, three circuit torque converter 11b is shown. Figure 22 shows the three circuit torque converter clutch disengaged, while Figure 23 shows the three circuit torque converter

clutch engaged. Three circuit torque converter 11b is shows having input shaft 13b, which is coupled to engine crankshaft 13, and output shaft 17b, which is coupled to transmission input shaft 17. Two circuit torque

5   converter 11b has converter clutch 200b. In Figure 22, fluid is supplied to both the impeller side and to the converter clutch control circuit of the converter; this prevents the clutch from being engaged. The purpose of orifice 202b on the converter inlet side is to reduce the

10   amount of pressure on the converter side of the clutch. The hydraulic pressure in the front chamber becomes greater than pressure in the rear chamber, holding the converter clutch away from the converter cover and releasing lockup. During lock-up mode, in Figure 23,

15   fluid is allowed to exhaust through the clutch control circuit, thereby allowing the converter clutch piston to apply. Hydraulic pressure in the converter side of the clutch causes the converter clutch to press tightly against the converter cover. Lock-up occurs, and power

20   is transmitted directly to transmission 15 with no fluid slippage. Converter in oil is fed directly, without an orifice. Converter output is restricted by orifice 204b to ensure the pressure builds up on the converter side of the lockup clutch.

25   The inventors of the present invention have found that torque converter 11a is more difficult to lock when transmitting large negative torque (impeller spinning much slower than turbine) than torque converter 11b. A potential explanation of this is that when the

30   impeller is spinning slower than the turbine, the turbine is pushing oil into the impeller, rather than the other way. It is then hard to build pressure on the turbine side to push the clutch on.

However, those skilled in the art will recognize, in view of this disclosure, that the method of the present invention is not limited to two circuit torque converters. In particular, this aspect of the present invention is applicable to any torque converter that would be difficult to lock when transmitting large negative torque values. For example, this difficulty may be due to inability to build hydraulic pressure or inability to exhaust hydraulic pressure. Typically, this type of torque converter has insufficient hydraulic pressure to be locked when transmitting a predetermined amount of negative torque. This predetermined amount of negative torque can be determined using torque converter input and output speeds. For example, when output speed is greater than input speed by a predetermined amount, the torque converter has insufficient hydraulic pressure to be locked.

Further, the inventors have recognized that it is possible to minimize "clunk" by providing an un-locked torque converter when passing through the zero torque point (or transmission lash zone). And, at the same time, provide maximum availability of negative powertrain torque with a locked torque converter by locking the torque converter after transitioning through the lash zone.